Titanium Structures for Army Systems

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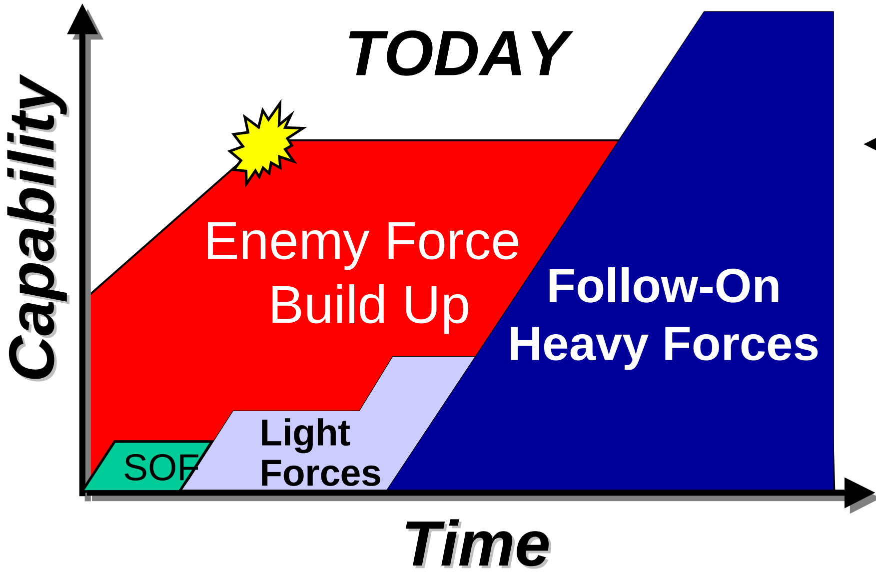
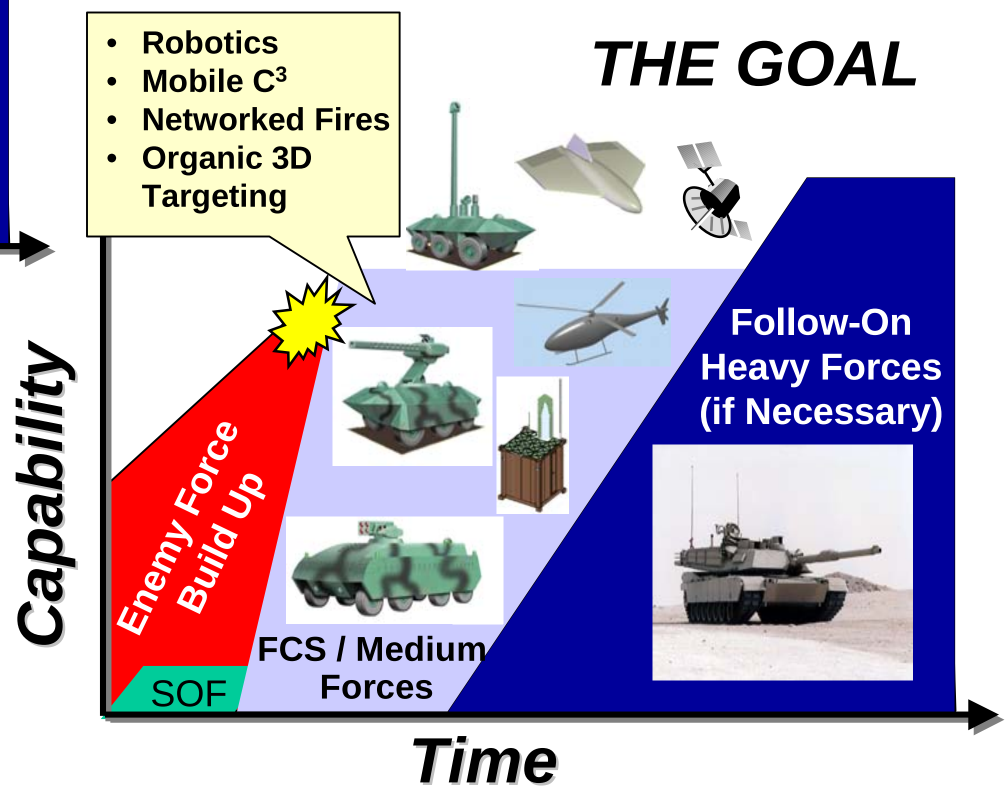
The Challenge: Lethal, Effective Early Entry Forces



Red overmatch sets the conditions of battle

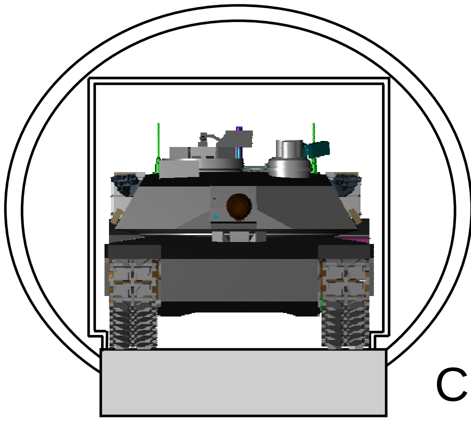
FCS
- **Multi-mission**
- **Rapidly deployed**
- **Light logistically**
- **Variable lethality**



Allows U.S. to set conditions on the battlefield

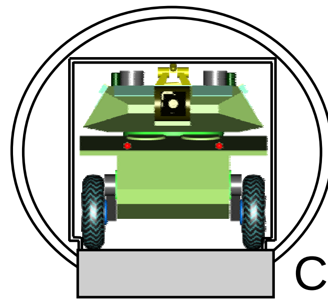
Objective Force Drivers

Operational Challenge - Moving the Full Spectrum Force



C17/C5

Science & Technology



C130

Up to:
70% Lighter
50% Smaller

Future Concept - FCS & FSCS
18 +/- Tonnes
8.5-11.5 m³ Internal Volume

Current System
54-64 Tonnes
18.5 m³ Internal Volume

Lighten the force, not just lighten the platform

Technology Challenges

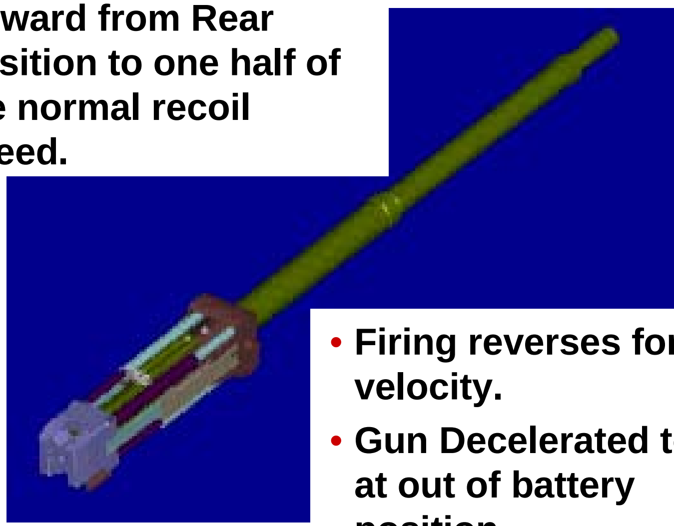
- **Survivability**
- **Lethality**
- **C4I**
- **Supportability**
- **Human Factors**
- **Mobility**
- **Training**

Notes for Slide 3

A key parameter that we will have to look at in arming the Full Spectrum Brigade is the available space within our airborne transportation assets. The best projections from our Army Staff studies on Strategic Maneuver indicate that we will probably not have a new transportation aircraft available for inter or intra-theatre lift in the 2010-2020 timeframe. Therefore, we will have to use existing air transportation assets to move the Full Spectrum Brigade - which drives us in size to a 20 ton/400 cubic foot vehicle that will fit in both a C130 and in commercial 747-class cargo aircraft. I echo the VCSA's comment that aiming for C-130 transportability is an excellent way to keep the FCV size and weight manageable.

Technology Driver: Lethality

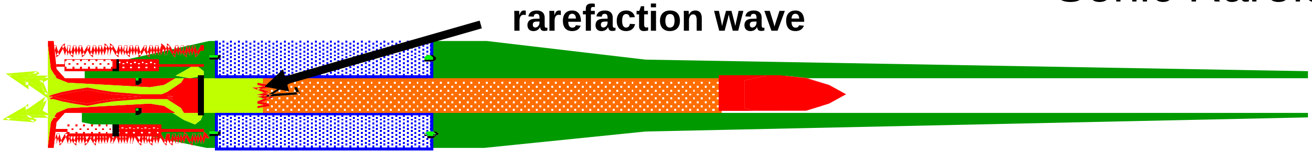
- **Gun Pre-Accelerated forward from Rear Position to one half of the normal recoil speed.**



- **Firing reverses forward velocity.**
- **Gun Decelerated to rest at out of battery position.**

The back of the gun may be uncorked when the projectile has traveled about one third the way down the gun with NO NEGATIVE EFFECT ON THE PROJECTILE PROPULSION. Can reduce recoil up to 75%.

Wave front of the sonic rarefaction wave



- Impulse of ammunition is increasing for lethality overmatch.
- Problem:
  - Trunnion Force = Impulse^2 / 2 M X
  - Lighting and reducing size to increase mobility.
- Techniques under development to mitigate recoil:
  - High strength trunnion and carriage materials.
  - Benign muzzle brakes.
  - Fire-out-of-Battery
  - Sonic Rarefaction Wave Gun

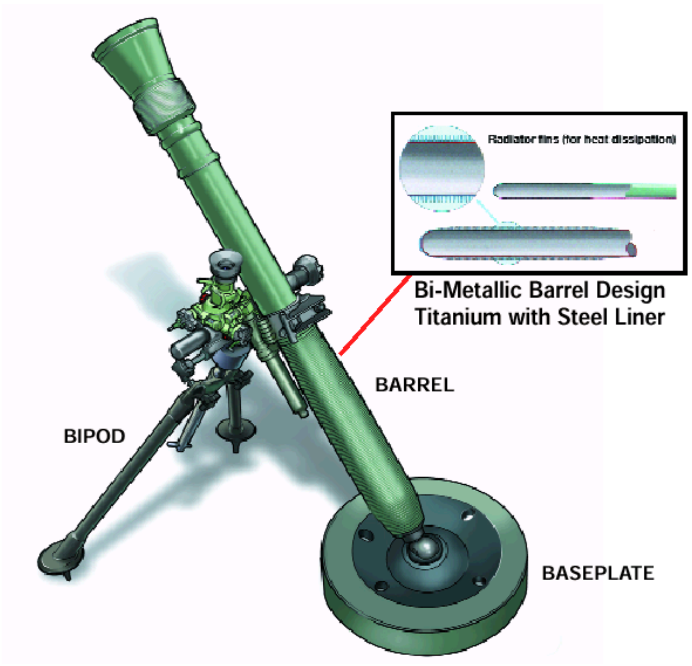
XM777

	M198	XM777
Weight	16,000lbs	9,000lbs
Max Rate of Fire	4 Rds/min	5 Rds/min
Emplacement Time	8 Min	3 Min
Displacement Time	11 Min	2 Min
C-130 Capacity* *Investigating C130 Capability to Transport Both the M1083 and XM777	1 Howitzer	2 Howitzers
Primer Mechanism	Manual Single Round	Auto-Primer Feed

- Active procurement programme.
- No “revolutionary” changes in basic howitzer design.
  - Novel transport configuration
  - Carriage constructed from Ti-alloy weldments.

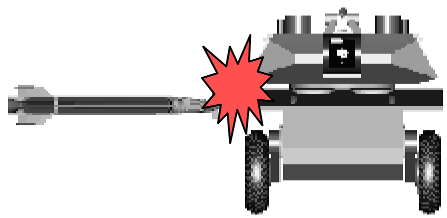
LWT 81mm Mortar System

- Man-portable design:
  - ~32 kg weight, 30% lighter than the M252 mortar system.
  - replace the M252 81-mm or even the M224 60-mm mortar.
- Features
  - Redesigned graphite-composite and titanium bipod.
  - A new baseplate featureing integrated aluminum and fiber-reinforced composite.
  - Bi-metallic steel and titanium tube.
    - will undergo firings to validate its structural integrity and robustness.



Technology Driver: Survivability

Survive first round engagement … don't be hit

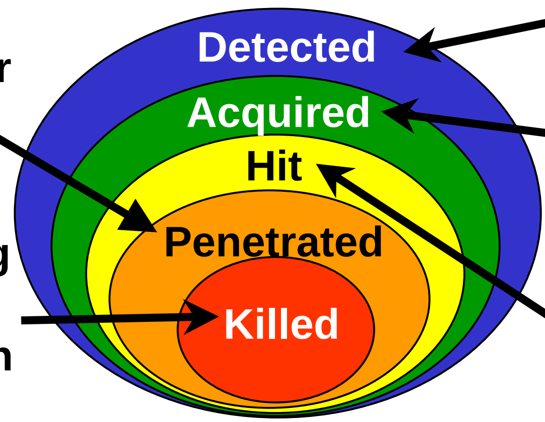


Momentum transfer issue

Don't Be ...

Passive armor
Reactive armor
EM armor
Smart armor

Compartmenting
Spall reduction
Fire suppression



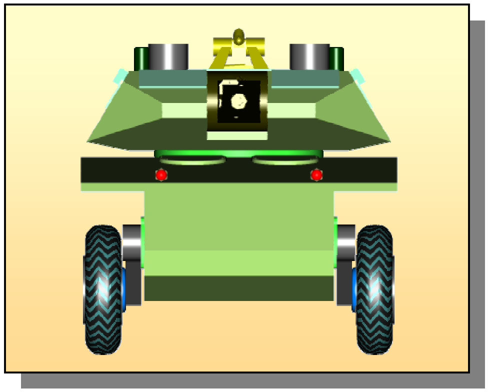
Signature reduction

Obscurants
Jammers

Jammers Decoys
Active Protection

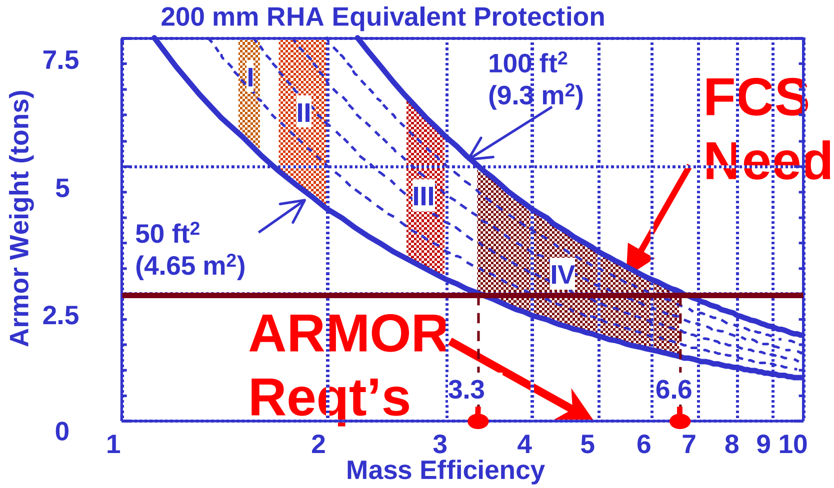
Requires:

- New Battle Concepts
- Technology Breakthroughs
- Novel System Design(s)



Achieving the paradigm requires innovative thinking

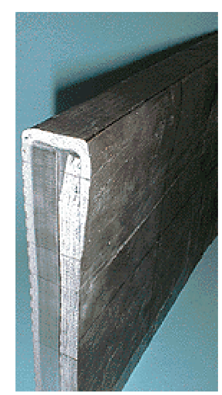
Composite Armoured Vehicle



Composite Armoured Vehicle

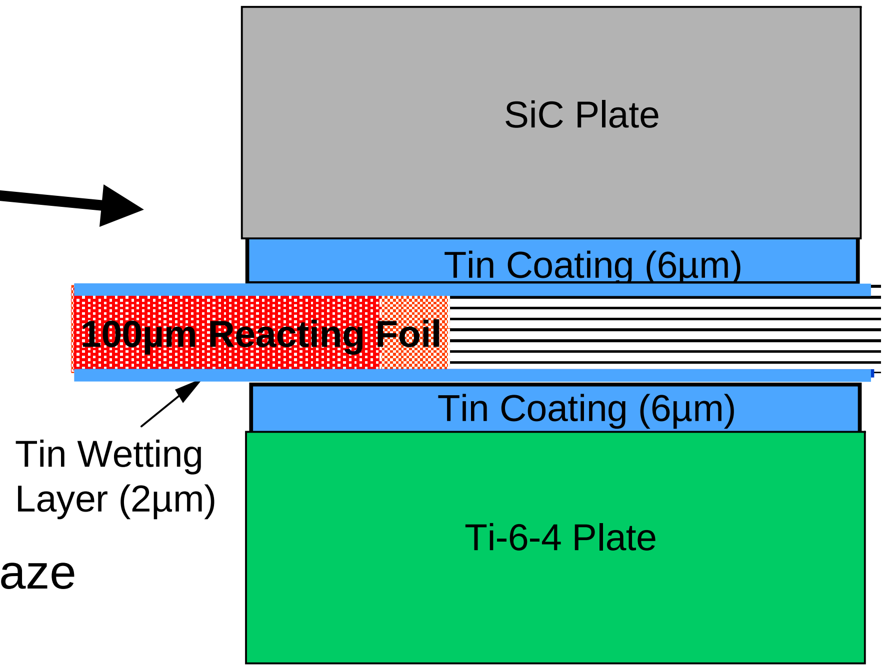
- Completed ATD Programme
- Best “off-the-shelf” armour system available now.
- System of choice for Crusader and candidate for FCS vehicles.
- Problems:
  - Expensive, long lead-times and etc.
  - Still heavy!

- **S2-Glass Epoxy Structure**
- **High Alumina Ceramic Armour plates**
- **Entire Structure Integrally Resin-Transfer Moulded**



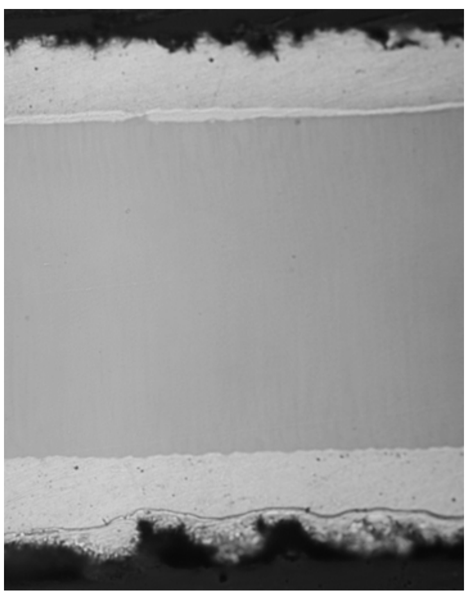
Joining Armor Materials with Reactive Multilayer Foils

- Goal: join armor materials using reactive multilayer foils as local heat sources as shown schematically



T. Weihs, E. Chin, S. Schoenfeld (ARL-WMRD)

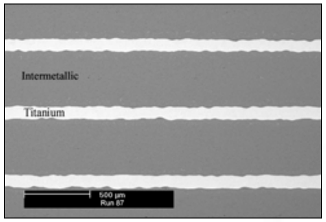
An Example: Cu-Cu Joint



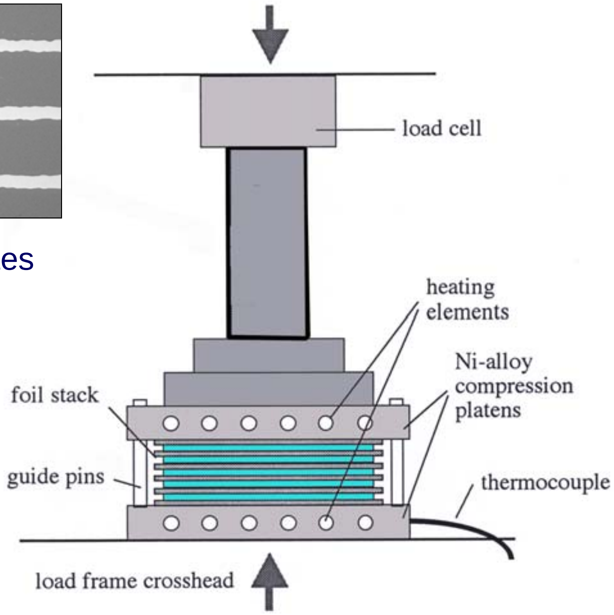
- A Cu to Cu joint with a thick reactive foil (~150µm) and thin braze layers. The outer Cu layers are approximately 40µm thick, and the joints have shear strengths greater than 30 MPa

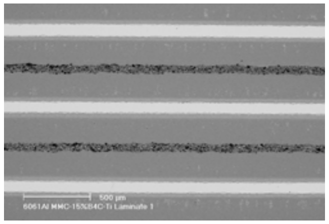
Ti-Al Metallic-Intermetallic Composites

- Fabrication
  - Alternating stack of Ti and Al foils
  - Reaction to form intermetallic layer structure
  - Final structure set by stacking
    - Ti + TiAl
    - Al + Al_3Ti
  - Automated processing for reduced processing time and reaction control
  - Additional particle reinforcement possible
- Structure-property correlation for strength and toughness optimization



Ti - Al Composites





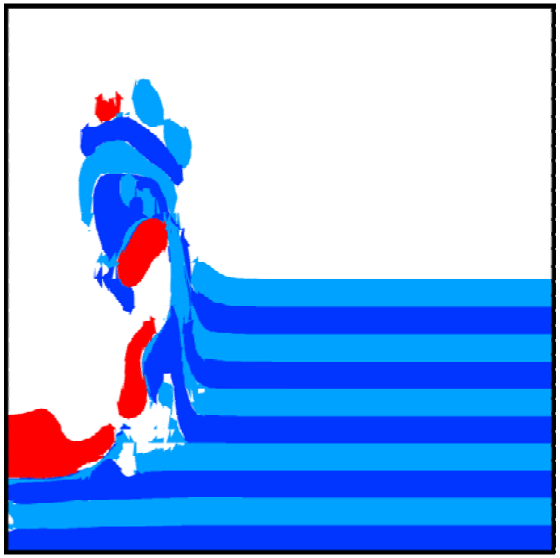
Ti - Al - Ceramic Particulate Composites

K. Vecchio (UC San Diego)

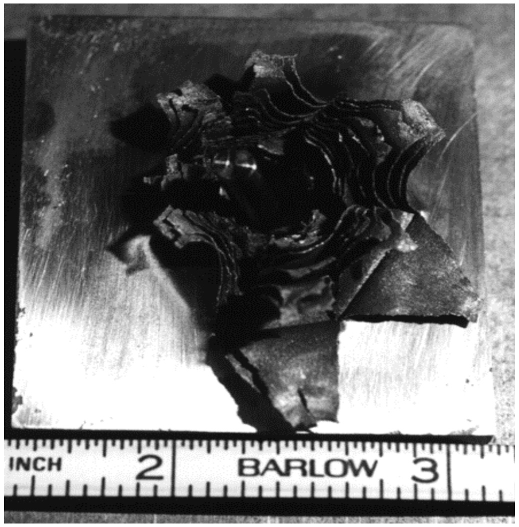
Laminated Armor Plates

K. Vecchio (UC San Diego)

Simulation showing defeat mechanism of hard/soft layers. Note lamella failure beneath projectile. Metallic layers bind hard phase to prevent ejection. Too soft of a metallic binder provides a “lubrication” effect though.



Ballistic test showing interlamellar failure mode in composite.

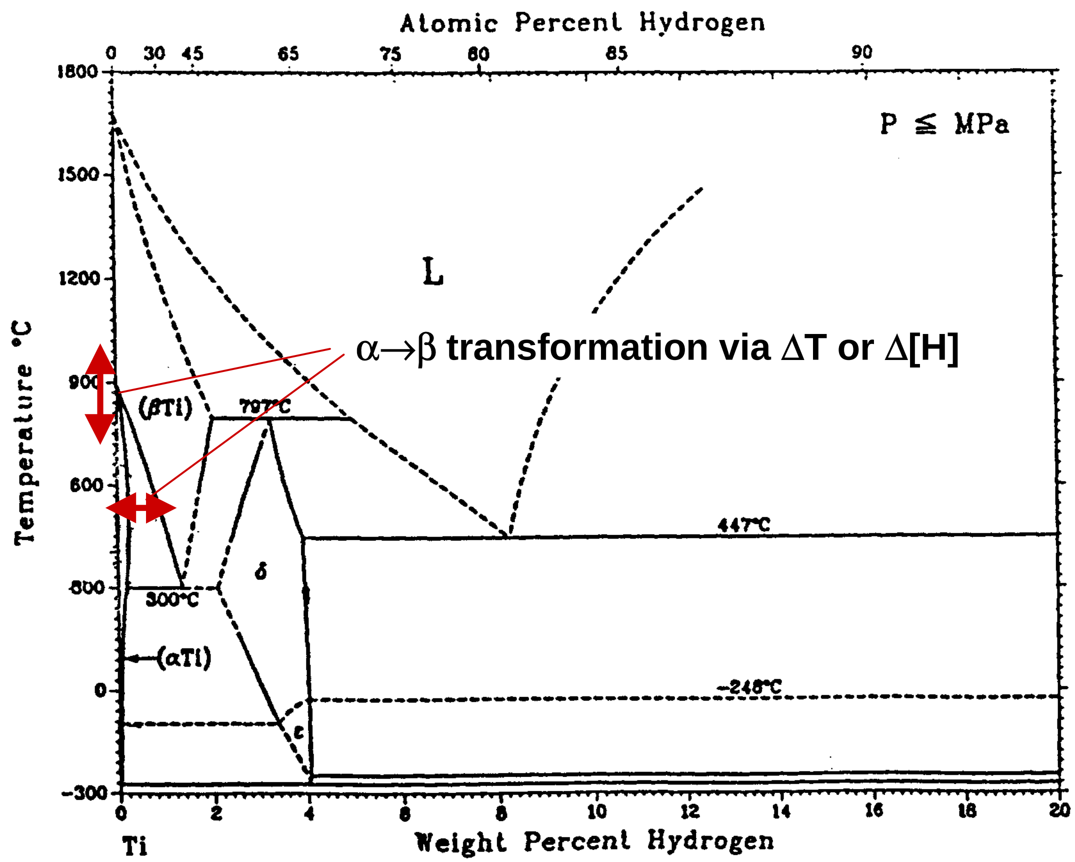


- Hard intermetallic layers break up and erode projectile.
- Metallic layers provide interlamellar failure mode, still binding the hard phase.
- Properties must be balanced for optimal ballistic performance

Transformation Plasticity

- OBJECTIVE: Increase plasticity Ti and Ti-matrix composite materials.

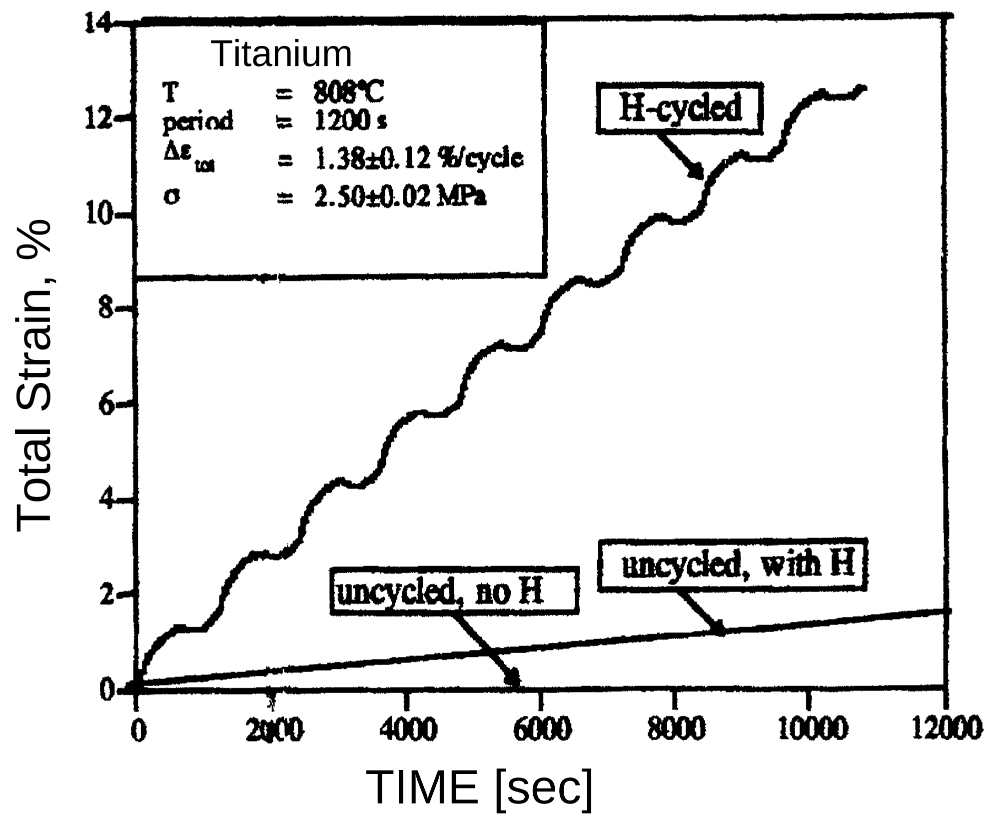
- APPROACH: Induce an allotropic transformation (ΔV) in one phase.
  - Cycle about the transition while under external stress.
  - Transformation stresses induce local plasticity and allow accelerated deformation.
  - Results in enhanced “creep forming” of alloys.



D.C. Dunand (N[W]U/MIT)

Transformation Plasticity

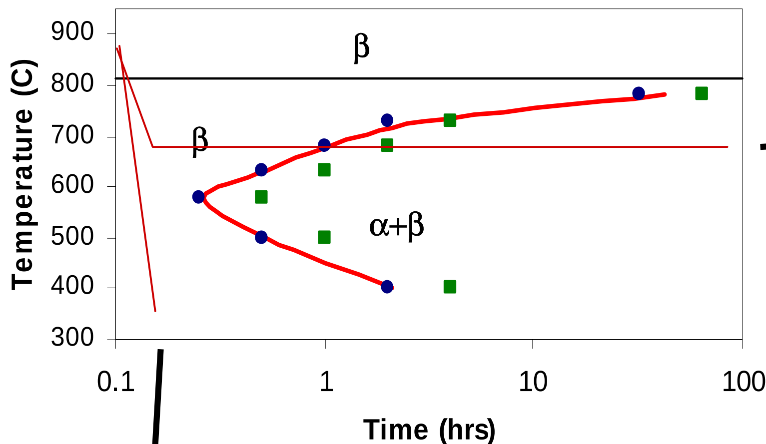
- ACCOMPLISHMENTS
  - Demonstrated TP in Ti/TiC MMC (matrix ΔT)
  - Demonstrated TP in Titanium (chemically driven $\Delta[H]$)
  - Theory of Transformation Plasticity extended from low stress linear regime to high-stress levels near the yield strength
- IMPACT
  - Enhanced creep formability for TiMC
  - Enhanced superplastic forming of Ti

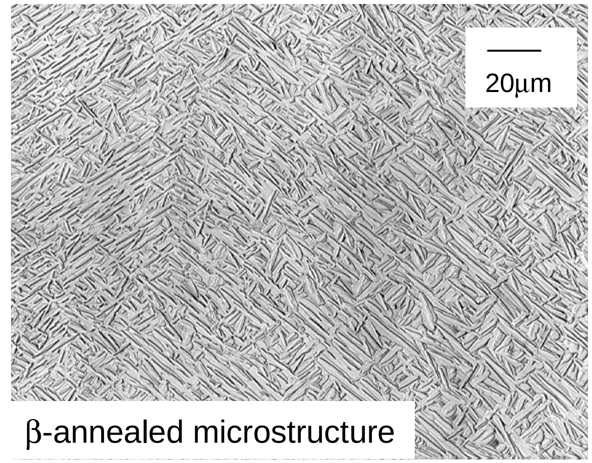


D.C. Dunand (N[W]U/MIT)

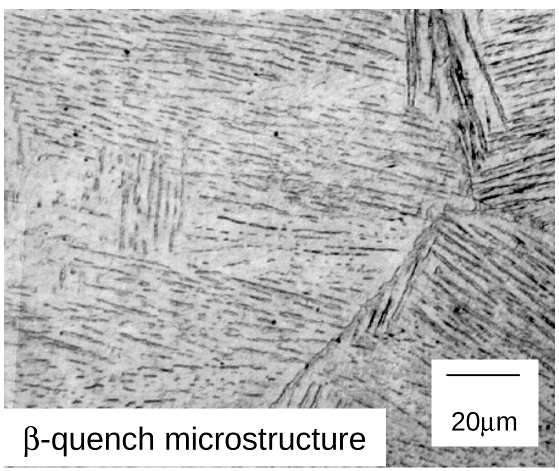
Thermohydrogen Processing

TTT Curve, Ti-64 (30 at.% H)





β-annealed microstructure



β-quench microstructure

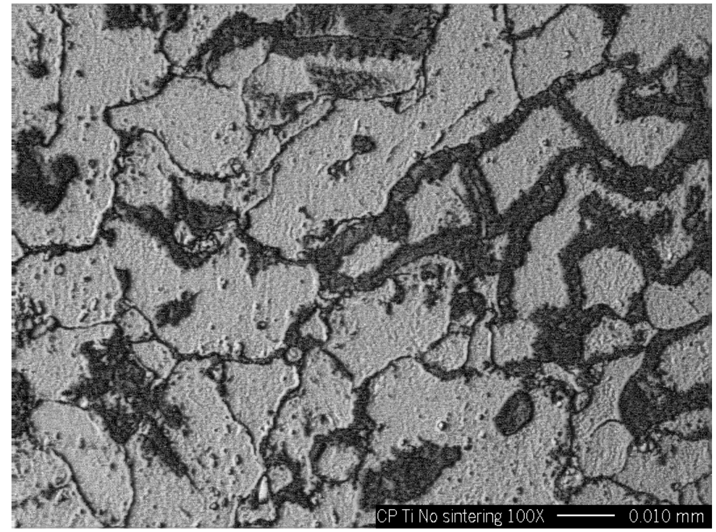
- APPROACH
  - Cast & HIP'd (890°C) Ti-6Al-4V plate
  - Hydrogenated 780°C 24 hrs to 30 at.% Hydrogen
- RESULTS
  - Reduction in grain size from 30-60mm to 1-3mm
  - Temperature decrease of 100°C to 200°C for hot working
  - Improved processability and machinability
  - Improved final mechanical properties.

F.H. Froes *et al*. (U. Idaho)

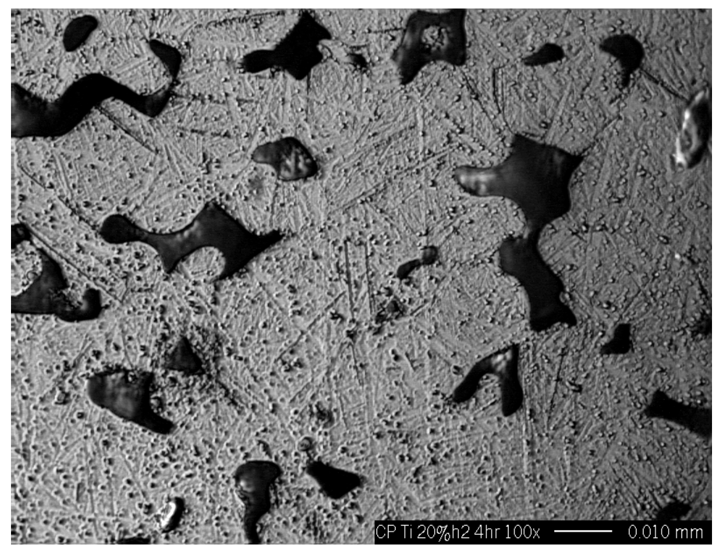
Effect of Hydrogen on Powder Sinterability

- OBJECTIVE: Hydrogen effect as Temporary Alloying Element on the Sinterability of Ti Powders.
- RESULTS
  - Preliminary Results to date.
  - Higher hardness for hydrogen-charged sample.
  - Higher sintered density for hydrogen charged sample.
- APPLICATIONS
  - Sinter-forged Ti-6Al-4V commander's hatch on M1 Abrams (SBIR project from ARL-WMRD)
  - Jet engine compressor rotors (possible)

CP-Ti Powder, Cold-Compacted to ~74% density.



Pressureless sintered at 900ºC for 4 hrs. Final density ~89%



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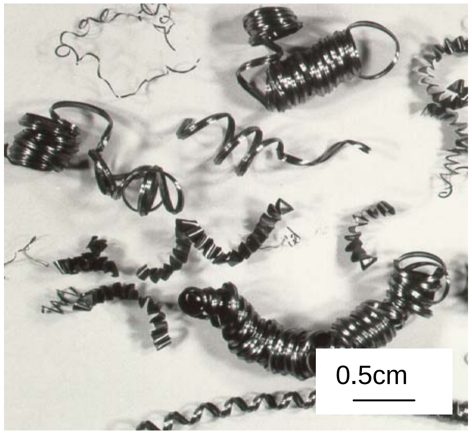
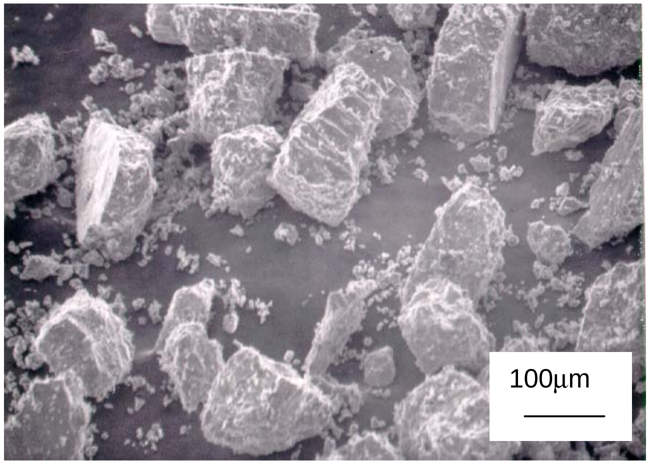
Scrap Conversion

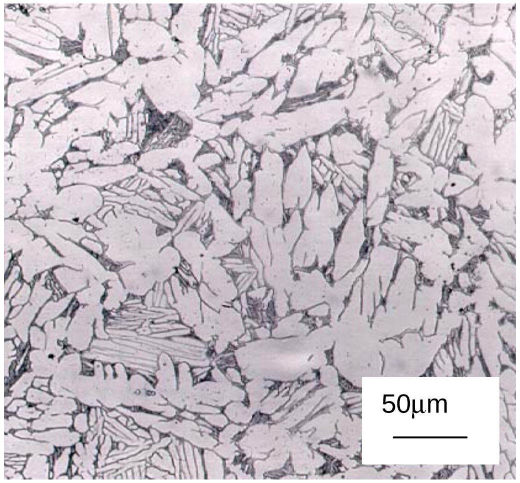


Scrap Ti turnings from aerospace fabricator.



TiH powder after grinding

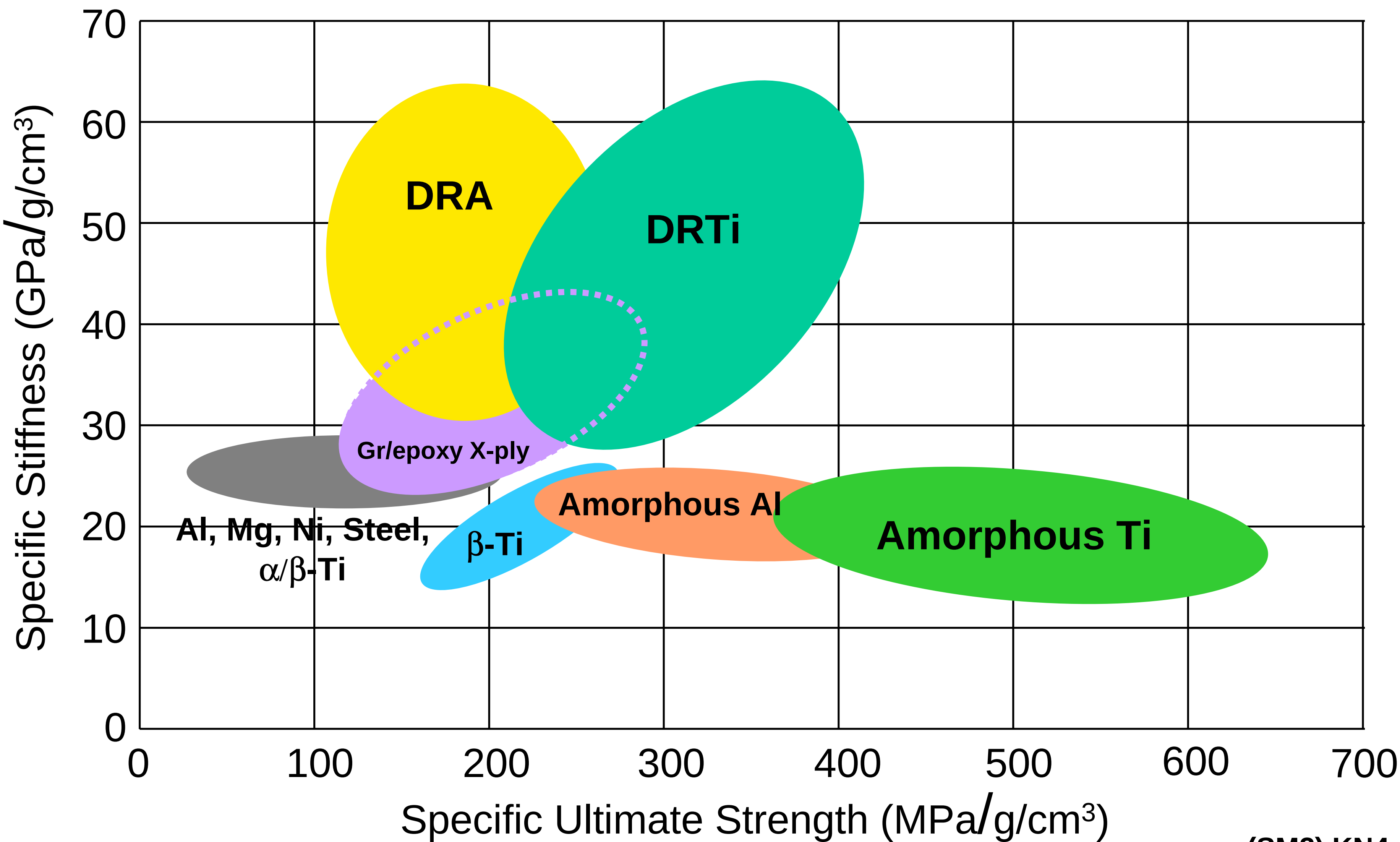
- Commercial turnings and scrap readily available for low cost.
- Clean and hydrogenate to brittle solid.
- Grind to form powder.
- Powder process with or without dehydrogenation to form components.
- Good microstructures and properties observed.



Microstructure after HIPing.

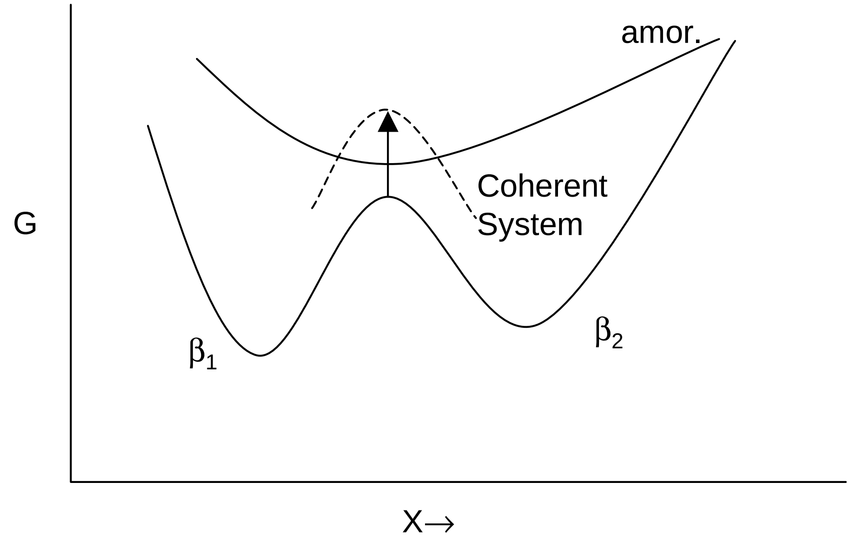
F.H. Froes *et al*. (U. Idaho)

Specific Properties



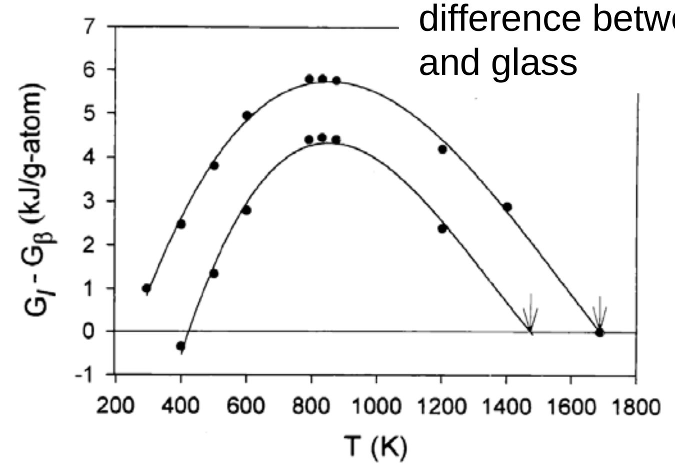
Ti-based Amorphous Alloys

- Amorphous powders formed by strong mechanical alloying.
- Amorphous bulk formed by spontaneous “melting” of crystalline phases.
  - Immiscible system, *ie.* Ti-Cr
  - Melt solidified to form single crystalline phase.
  - Once cooled deep into miscibility gap, two-phases spontaneously emerge.
  - Coherency strains of two phases increase free energy of system, to higher than amorphous phase.
  - System metastability maintained by diffusion-limited kinetics.



G. Schiflet (UVa)

DCS measured Free-Energy difference between β phase and glass



Conclusions

- Long history of Ti R&D in the U.S. Army.
- Cost has been a major barrier to Ti usage.
- Ti-alloys are finding application in developmental gun systems.
  - Light weight overrides cost issues.
  - Significant design challenges posed in gun applications.
- Current Ti research looks at reducing processing costs.
- New Ti alloys (and metallic glasses) promise to revolutionize Ti applications.
- Future looks good for including structural Ti in U.S. Army ground systems.